208

NASA TECHNICAL TRANSLATION NASA TT F 15,406

IMPROVEMENT OF MANEUVERABILITY AT HIGH SUBSONIC SPEEDS

W. Staudacher

(NASA-TT-F-15406) IMPROVEMENT OF MANEUVERABILITY AT HIGH SUBSONIC SPEEDS (Scientific Translation Service) ~~24~~ 22 p HC $4.25 CSCL 01C

N74-17757

Unclas
G3/02 31778

Translation of: "Verbesserung der Manöverleistungen im hohen Unterschall," Deutsche Gesellschaft fur Luft und Raumfahrt, Symposium uber Tragflugel-Aerodynamik bei Schallnahen Stromunger, Gottingen, West Germany, Paper 72-126, October 26, 27, 1972, 24 pp.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D. C. 20546 MARCH 1974

SUMMARY

MBB-UFE has carried out a number of experimental studies for improving maneuver performance of fighters. Geometrically variable configuration changes were carried out on a pilot model and the use of leading edge and trailing edge flaps with and without a slot were tested in the transonic range. One of the fixed geometric variables was to apply strakes, leading edge modifications with high sweepback, in the wing root area. This was investigated over the entire Mach number range (six component measurements).

By combining the maneuver aids, we were able to achieve performance improvements of more than 100% compared with the basic wing for certain flight ranges. The efficiency of the strake in the area of high angles of attack greatly exceeds the efficiency of the flap system.

NOTATION

A	Lift
C_A	Lift coefficient
$C_{A_{B.O}}$	Buffet onset lift coefficient
$C_{A_{max}}$	Maximum lift coefficient
C_{A_α}	Lift increase (linear)
$C_{A_{\alpha_{local}}}$	Local lift increase $= \left. \frac{dC_A}{d\alpha} \right\vert$
C_W	Drag coefficient
C_{W_i}	Coefficient of drag dependent on lift
d/l	Relative profile thickness
F_{id}	Ideal area (up to central section)
F_{Bez}	Reference area = ideal area of basic wing
g	Acceleration of gravity = 9.81 m/sec^2
HLW	Elevator
K	Drag factor $= \left. \frac{\partial C_W}{\partial C_A{}^2} \right\vert$
$l\mu$	Average aerodynamic chord
l_{Bez}	Reference length = $l\mu$ of basic wing
Ma	Mach number
N	Normal force

n	Maneuver multiple [g]
S	Suction force
U_∞	Incident velocity
$V_{max/min}$	Maximum/minimum velocity
W	Drag
WBM	Root bending moment
α	Angle of attack
Δ ( )	Inclement of ( )
δ_K	Trailing edge flap angle, positive downwards
δ_V	Leading edge flap angle, positive downwards
Λ	Aspect ratio
λ	Sharpness
φ_0	Leading edge sweepback
$\varphi_{1/4}$	Sweepback of 25% line

IMPROVEMENT OF MANEUVERABILITY AT
HIGH SUBSONIC SPEEDS *

Werner Staudacher

1. INTRODUCTION /1*

1.1. Summary

There are a number of criteria which can become limiting for the maneuverability of a fighter. If we do not consider the restricted amount by which a pilot can be loaded as well as the structural limits, then often one of the following phenomena (or several of them) means that the maximum lift of the aircraft cannot be exploited (see Figure 1, shaded region):

a) Buffet (shock-induced separation)
b) Wing rock (probably a form of asymmetric buffet which produces a short period of instability around the roll axis)
c) Wing drop (separation of wing flow on one side with subsequent roll-yaw motion)
d) Nose slicing (short period asymmetrically excited yaw instability
e) Pitch-up (Longitudinal moment instability by separation of the flow at the wing tips of sweptback wings)

* Report No. UFE-896-72 (Ö) Messerschmitt-Bolkow-Blohm GMBH Contribution to the DGLR Symposium on "Wing Aerodynamics for Flows near Acoustic Velocity". Gottingen, October 26-27, 1972. DGLR 72- 126.

** Numbers in the margin indicate pagination of original foreign text.

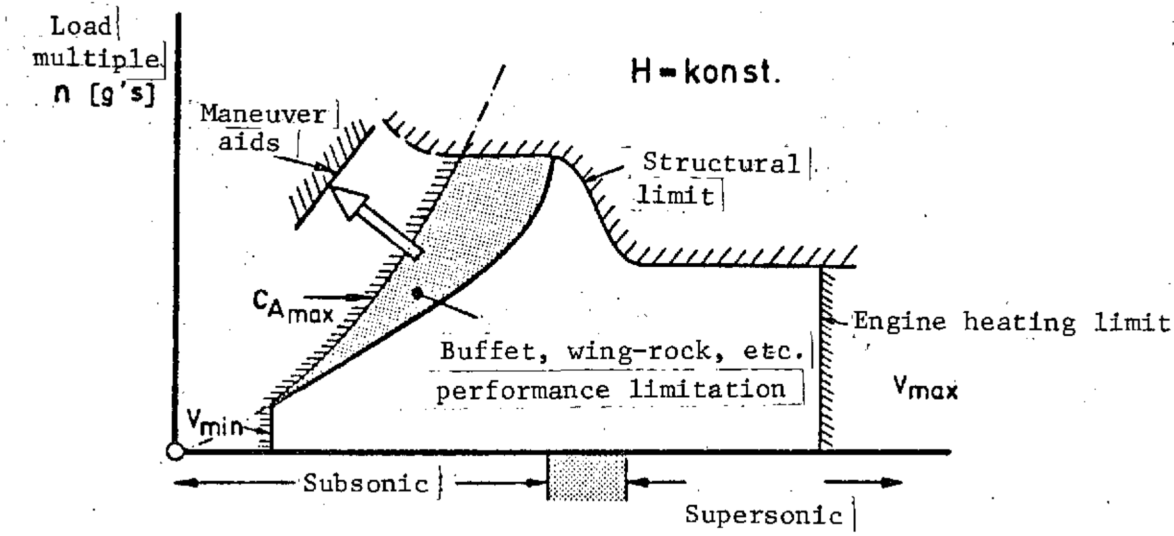

Figure 1. Maneuver limits of a fighter

f) Side stability loss at high angles of attack

g) Ineffectiveness of roll control at high angles of attack

h) Drag increase, etc.

Some type of flow separation is responsible for all of these phenomena. One has the choice of preventing it with the classical methods (curvature flaps or gap flaps) or to produce control separation and even exploit it (strakes, planing fins, canard surfaces which interact with the wing, etc.) The first method leads back to a linear wing (potential theory) and the second method leads to the nonlinear wing. Figure 2a shows these two cases. In the present paper we will consider both methods and compare them. /2

1.2. Influence of Wing Geometry on Buffet Onset Characteristics

Ray and Taylor [1] systematically investigated the influence of the wing geometry on buffet onset characteristics.

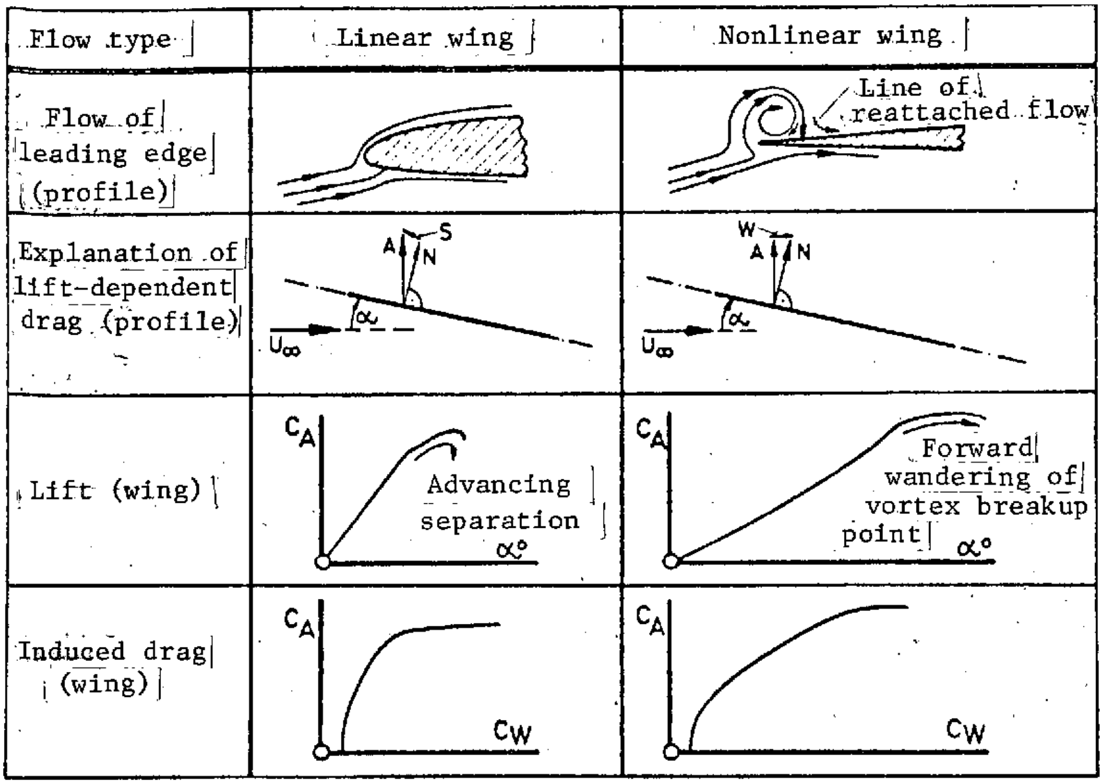

Figure 2. Comparison of flow types

Figure 3 shows the summary given in reference [2].

The top part of the figure shows the conditions for Ma = 0.50. The following have a favorable effect on buffet onset properties: increase of curvature, twist, elongation and relative profile thickness. Reduction of sweepback and thickness backward displacement also have the same general effect.

For Ma = 0.85 (lower half of Figure 3), the tendencies which the aspect ratio, thickness, sweepback and thickness rearward displacement produce are reversed. However, the curvature and the twist (wing warp) still have the same effect. The greatly reduced influence of increased curvature is remarkable. The basic

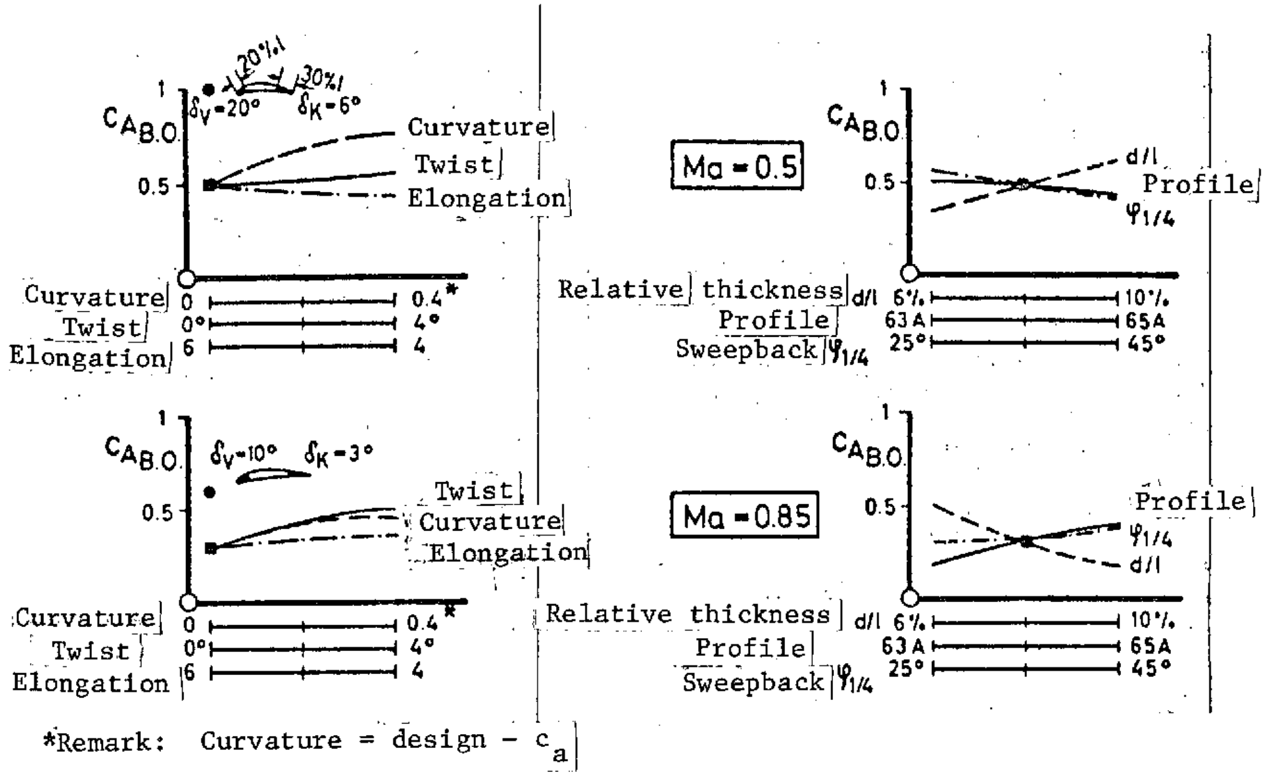

Figure 3. Influence of wing geometry on buffet onset

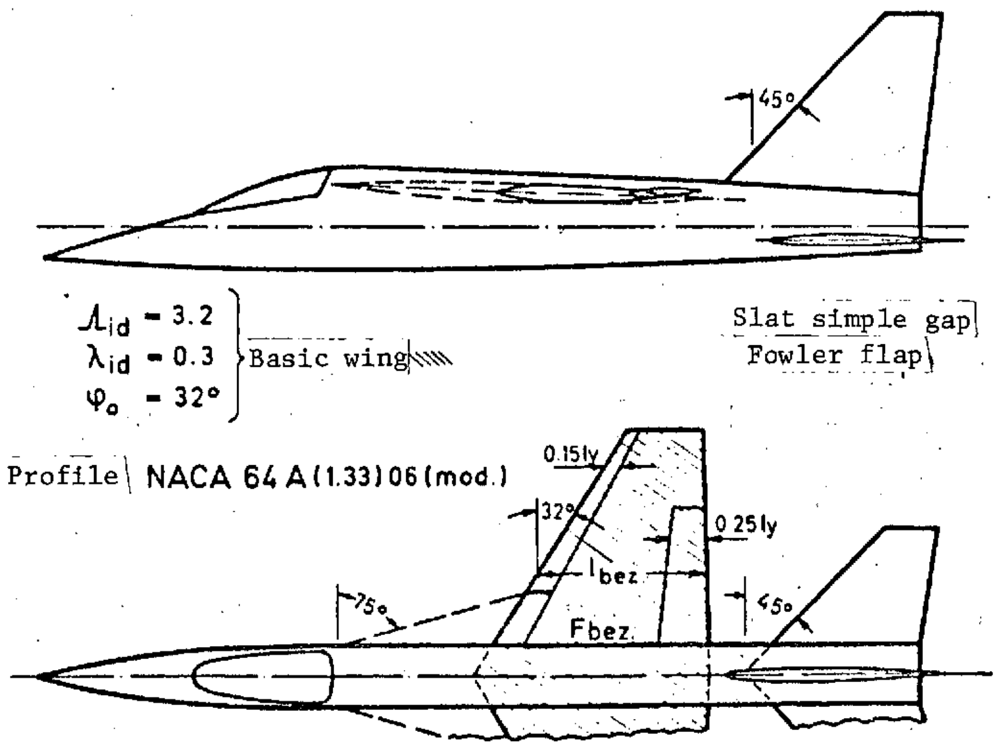

Figure 4. Pilot model geometry

wing (symbol ■) is defined by $\Lambda = 6$, $\varphi_{1/4} = 35^{\circ}$, $d/l = 8\%$. The twist and curvature are equal to zero and the profile is NACA 64 A 008. The results for the basic wing with curvature flaps at the leading edge and trailing edge are also shown, which result in 100% improvement in $C_{A_{B.O}}$ for both Mach numbers (for reduction of the flap deflections by one-half for the transition Ma = 0.5→0.85, according to the tendencies mentioned above for excessively large profile curvature).

2. PILOT MODEL

The high wing model (Figure 4) was built at the AVA-Göttingen and measured. A 1:5.5 model was built as a low velocity model for the 3m x 3m wind tunnel as well as a 1:20 transonic model for the 1m x 1m transonic tunnel.

The basic wing consisted of a thin trapezoidal wing $\Lambda = 3.2$, $\varphi_o = 32^{\circ}$, $\lambda = 0.30$, which could be fitted with gap flaps or curvature flaps (15% core) at the leading edge as well as simple gap flaps (25% core) with a Fowler ratio of 7.5% over 65% of the span of the trailing edge. The basic profile was NACA 64 A 006, which was modified over the span by a moderate amount of curvature and twist, and the thickness was also changed. In the wing root area, it was possible to change the cross section using a relatively sharp strake with a leading edge sweepback of 75° which could be mounted.

In order to measure the buffet characteristics, we use strain gauges in the root area and two series of pressure taps at the wing trailing edge. The expected pitch-up tendencies of the strake wing had to be equalized and we used two low elevators for this.

The test Reynolds numbers were in the range of $1.5 \div 2 \times 10^6$ for both models (for 1μ of the basic wing). The reference area for all coefficients is the ideal wing area of the basic wing (shaded in Figure 4), unless otherwise stated.

3. RESULTS: Lift and Drag Behavior

3.1. Comparison of Basic Wing With and Without Flaps

The influence of the maneuver flaps on the subsonic and transonic characteristics has been the subject of intensive experimental investigations in recent times. This was done in particular to prove the maneuver performance of the Phantom F4. The gains achieved were considerable, as far as buffet onset, drag behavior and side stability are concerned (see references [2] and [4]).

3.1.1. $C_A = f(\alpha)$, $C_A = f(C_W)$.

Figure 5a and 5b show the results for Ma = 0.5 and 0.95. $C_A(\alpha)$ is shown as well as the drag polar $C_A(C_W)$ for the pilot model with and without maneuver flap system. It is found that the flap wing has almost the same effect between Ma = 0.5 and 0.95 at high angles of attack. This is true for the lift as well as for the induced drag. Beginning at $\alpha \approx 6^\circ$, the maneuver wing is more effective (intersection of the polars).

3.1.2. Lift and Maneuver Limits

Figure 6 shows the influence of the leading edge and trailing edge flaps on $C_{A_{max}}$ (this corresponds to the left limiting curve in Figure 1) as well as on the buffet onset C_A (which amounts to the right limit of the shaded region in Figure 1).

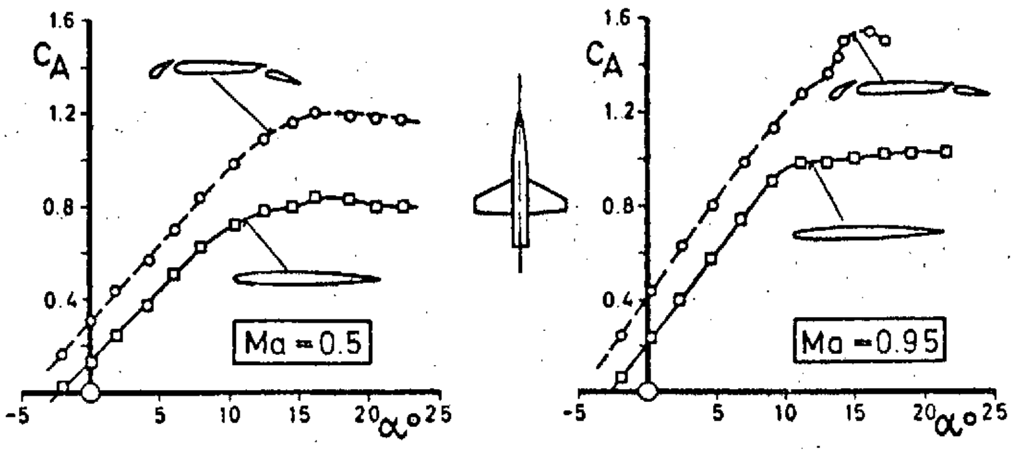

Figure 5a. Comparison: Lift clean/man. configuration
Basic wing/without HLW

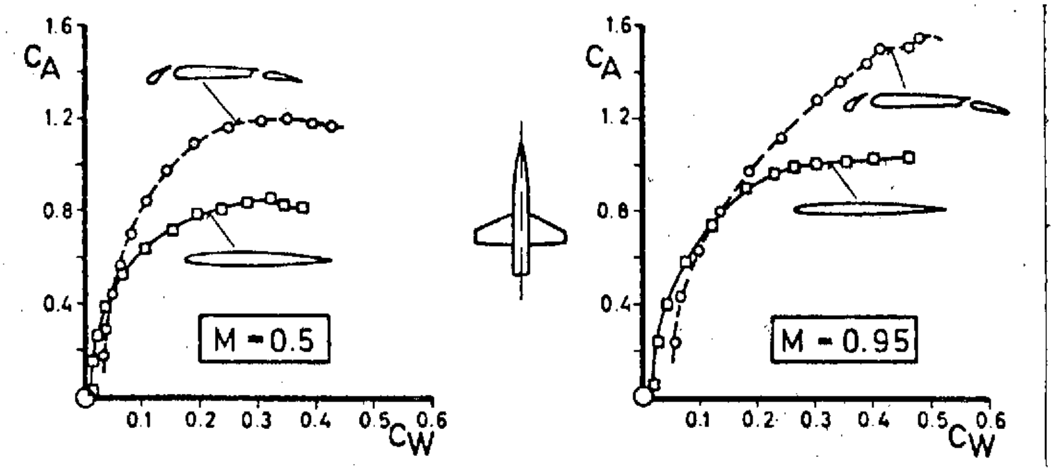

Figure 5b. Comparison: Drag polar clean/man. configuration
Basic wing/without HLW

The $C_{A_{max}}$ curve as well as $C_{A_{BO}}$ of the clear wing are typical for thin trapezoidal wings as a function of Mach number (see Starfighter F104G).

The slat results in a 60-65% improvement in the absolute or usable lift increase. The remainder can be attributed to the trailing edge flap. The maneuver flaps result in practically constant increments as a function of Mach number. They are more effective for improving the buffet properties than in increasing $C_{A_{max}}$ ($\Delta C_{A_{BO}} > \Delta C_{A_{max}}$).

3.2. Comparison of Basic Wing and Strake Wing

3.2.1. Wing without Flaps

Figure 2 already shows the principal differences between the flow around a sharp, strongly swept back strake and around the basic wing. In contrast to the usual sharp edged double delta wings, for which the outer and inner panels do not operate linearally, in the case of the strake wing, an attempt was made to provide a linear outer panel (basic wing) in combination with a nonlinear inner panel (strake) which produces a strong leading edge vortex. This amounts to a "mixing" of potential flow and flow of a separated vortex system over the wing. The induced drag represents a disadvantage of the nonlinear wing (sharp leading edge → separated cone vortex → loss of suction force). For small angles of attack, it was possible to avoid this disadvantage by an appropriate selection of the strake geometry and profile of the basic wing. Figure 7 also shows the theoretical results which are based on an extension of the Polhamus suction force analogy for sharp edged delta wings [3] to double delta and strake wings [7]. Figure 8 shows the net effect of a strake on the lift and drag behavior of the wing. Figure 8 on the

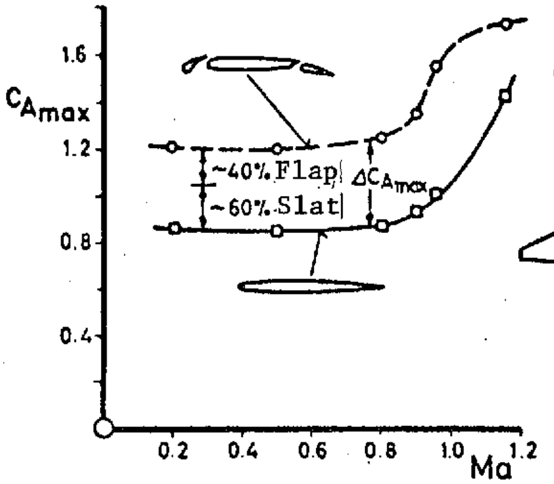

Figure 6. Lift and maneuver limits. Basic wing/without HLW

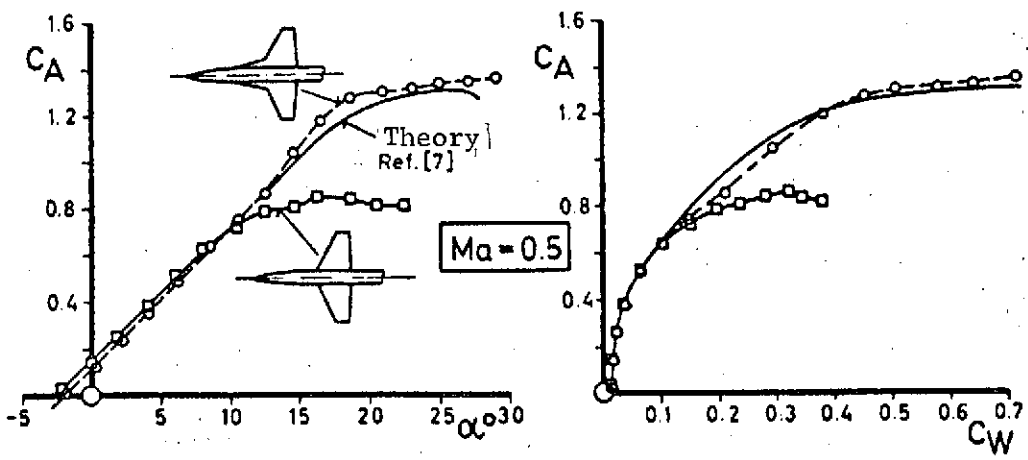

Figure 7. Comparison: Strake/basic wing, clean without HLW

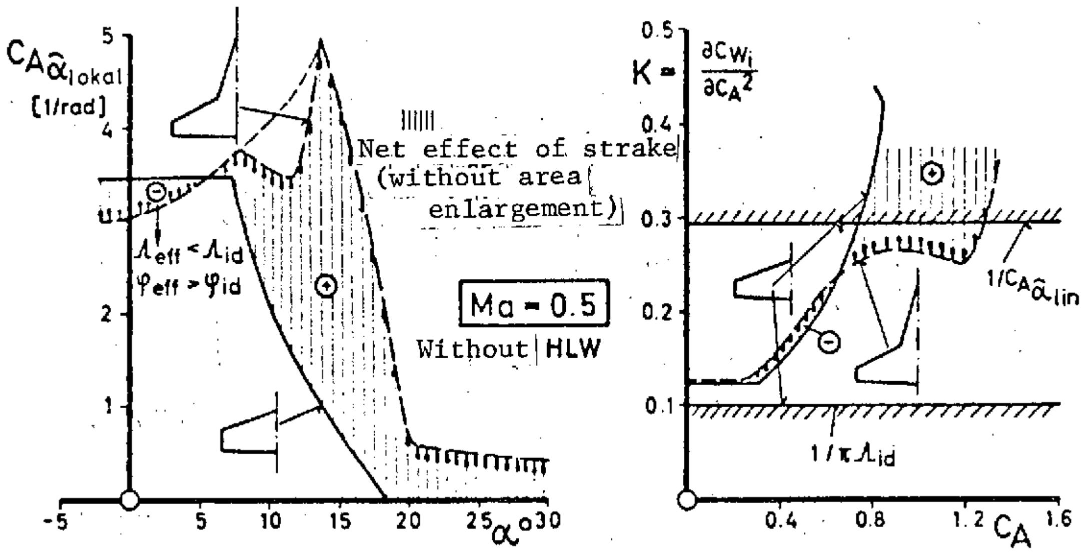

Figure 8. Net effect of strake

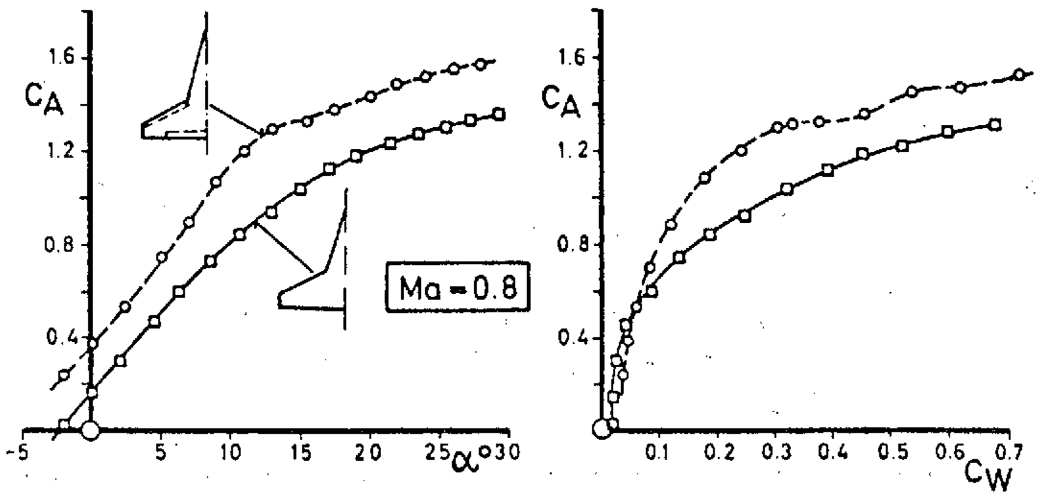

Figure 9. Effect of maneuver flaps at strake wing without HLW

left shows the local lift increases of the basic wing and the basic wing + strake. There is about a 10% area increase because of the strake, which was not considered because the reference area = area of ideal wing (see Figure 4) was not considered. However, this was eliminated in the calculation (same washed wing areas). To the left of the two curves, ($\alpha < 6^\circ$) the smaller effective aspect ratio and higher effective sweepback of the strate wing bring about a reduction in the lift increase which is desirable considering the Ridequalities* for low flight (gust sensitivity). The gradually increasing additional lift /6
of the strake vortex system then causes the further variation of the curve of local lift increase to occur for the strate wing (dashed). The difference between the two curves represents the net effect of the strake. On the right side of Figure 8, we show the induced drag factor $K = \frac{\partial C_{Wi}}{\partial C_A^2}$ as a function of angle of attack. After $C_A = 0.65$ corresponding to $\alpha \approx 8^\circ$ (bend in the $C_{A\alpha}$ curve of the basic wing on the left side of Figure 8) the strake brings about a substantial improvement in the induced drag. The overlapping of the K factors for $C_A \leq 0.3$ shows that it has been possible to suppress the undesirable nonlinear effect to a great extent. In other words, it has become possible to obtain the leading edge suction force. On the other hand, the positive influence of the nonlinear lift could be completely exploited in the range $C_A > 0.65$ (reversal of the inclination $\left.\frac{dK}{dC_A}\right)$. The lower limit $1/\pi\Lambda_{id}$ represents the ideal case (potential flow, elliptical circulation distribution, flow suction force); the upper limit $1/C_{A\alpha lin}$ represents the case of complete loss of leading edge suction force, always referred to the basic wing.

* Translator's note: Misspelled English word?

3.3. Strake Wing With and Without Flaps

3.3.1. $C_A = f(\alpha)$, $C_A = f(C_W)$

The flap system is identical with that of the basic wing, up to the part of the leading edge covered by the strake. There are no leading edge flaps on the strake itself. Figure 9 shows a comparison to Figure 5 and gives the reduced influence of the maneuvering flaps on $(\Delta C_{A_{max}})_{Man}$ compared with the basic wing without the strake. This is based on the following: /7

a) Low elongation of the slat in the span direction

b) The cone vortex which increases in intensity with angle of attack interferes with the vortex rotating in the opposite direction, which starts at the protruding side edge of the slat in the region of the leading edge inflection point.

3.3.2. Lift and Drag Increments Because of Strake (Trim State)

The trend mentioned above can be followed even better in Figure 10. This shows the lift and drag increments due to the strake for the clear wing and maneuver wing. The positive effect of the strake is displaced to higher angles of attack when the efficiency of the basic wing is increased (→ maneuver flaps). The lift increment over the flap wing reduces to about 40% of the amount for the clear wing (Figure 10 left). The drag increment (Figure 10 right) shows this by the small increase over a large angle of attack range. However, it is not permissible to draw a general conclusion from this. Certainly the flap system selected for the basic wing, which had to be retained, is not optimum to begin with for the strake wing. If it becomes

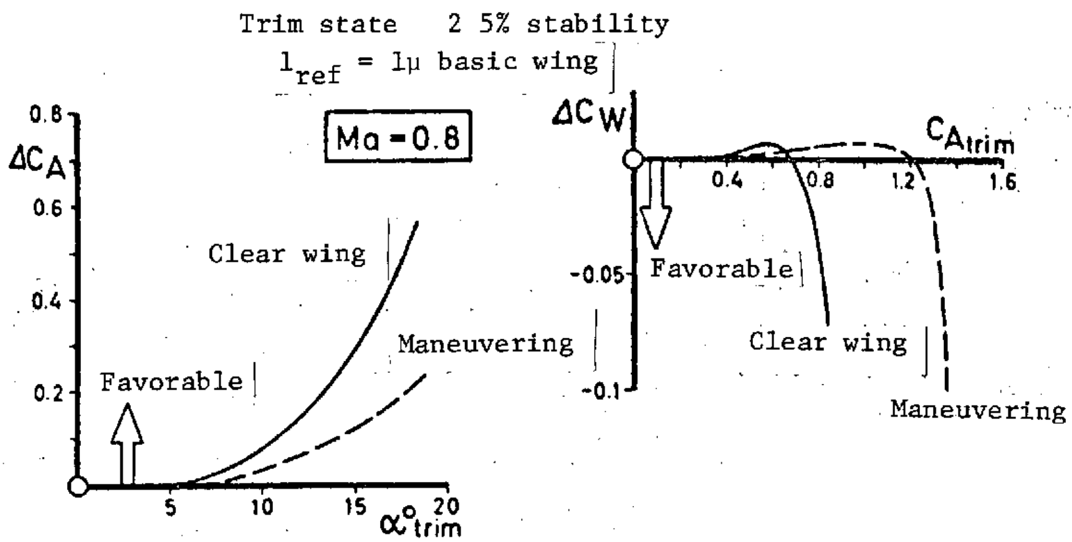

Figure 10. Lift and drag increments due to strake for clear and maneuver wing, trim state

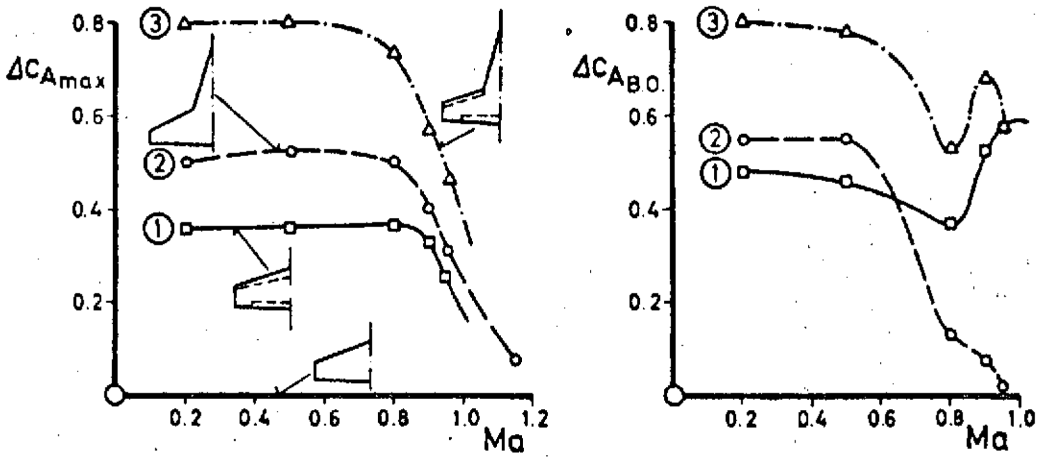

Figure 11. Improvement of maneuver limits by flap system and/or strake (Reference: Basic wing, clean) without HLW

possible to no longer consider the strake as an added device but to integrate its shape and profile into the entire wing, we will expect substantial improvements.

3.4. Comparison of the Lift and Maneuver Limits

Based on the results for the basic wing without flaps, we will now compare increments caused by maneuver flaps in the basic wing, strake + basic wing and strake wing + flap system. The abscissa in Figure 11 shows the clear basic wing with $\Delta(\ )=0$. /8

3.4.1. Lift Limit $C_{A_{max}}$ (Figure 11 Left)

In the Mach number range $Ma < 0.8$ it is possible to practically add the increments due to the flap system and the strake, i.e., Curve 3 (= wing with strake + maneuver flaps) can be considered as an addition of Curve 2 (= strake increments) and Curve 1 (= increments of the maneuver flaps for the basic wing) if we consider the lower span of the slat.

3.4.2. Maneuver Limits $C_{A_{BO}}$

Figure 11 on the right shows a comparison of the various increments for buffet onset. The addition of the increment properties mentioned above applies for $Ma > 0.8$. The improvement brought about by the strake as well as by the maneuver flap system are substantial. The effect of the strake is greater than that of the maneuver flaps in the subsonic range. By combining the strake and the flap system, it is possible to obtain gains of more than 100% in $C_{A_{BO}}$, compared with the clear basic wing. However, not only are the absolute $C_{A_{BO}}$ values improved by the strake, but there is a considerable reduction in the buffet intensity over the entire Mach number range, which is shown by a comparison of the solid curves in Figure 12 left (clear basic wing) and Figure 12 right (strake wing).

3.5. Comparison of Basic Wing - Strake Wing in Supersonic Range

Because of the low backward migration of the neutral point of a strake wing when it penetrates into the supersonic range (Figure 13 left), the supersonic trim drag values are reduced substantially (Figure 13 right). This means an approximately 20% reduction of the trimmed induced drag in a supersonic range for the case indicated Ma = 1.6. In addition, the increased effective sweepback and the increased slenderness of the strake wing bring about a reduction in the wave drag of the configuration (in the present case, which is not optimized for cross section, it is about 6-7%). The Mach number of /9
the drag increase is increased by about the same percentage.

4. CONCLUSION

Leading edge and trailing edge flaps are an effective maneuver aid down into the transonic flight range. The combination of a greatly swept back leading edge strake and a moderately swept back thin basic wing represents a very promising solution for improving the maneuver performances at high angles of attack, over the entire Mach number range. If it becomes possible to obtain more information on the flow processes over these wings, and to therefore integrate the strake in the entire configuration, it will become possible to obtain gains which are much greater than those obtained in this first experiment.

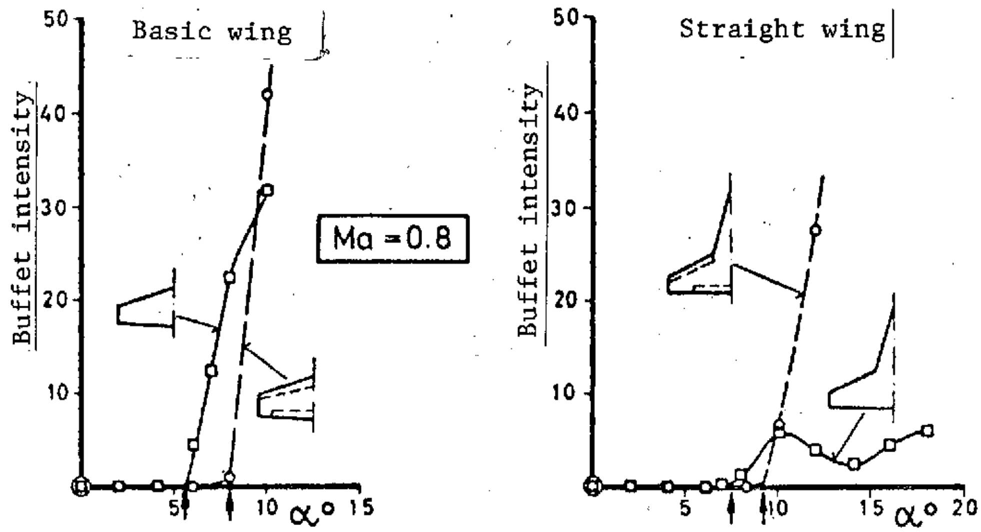

Figure 12. Buffet onset, divergence of root bending moment

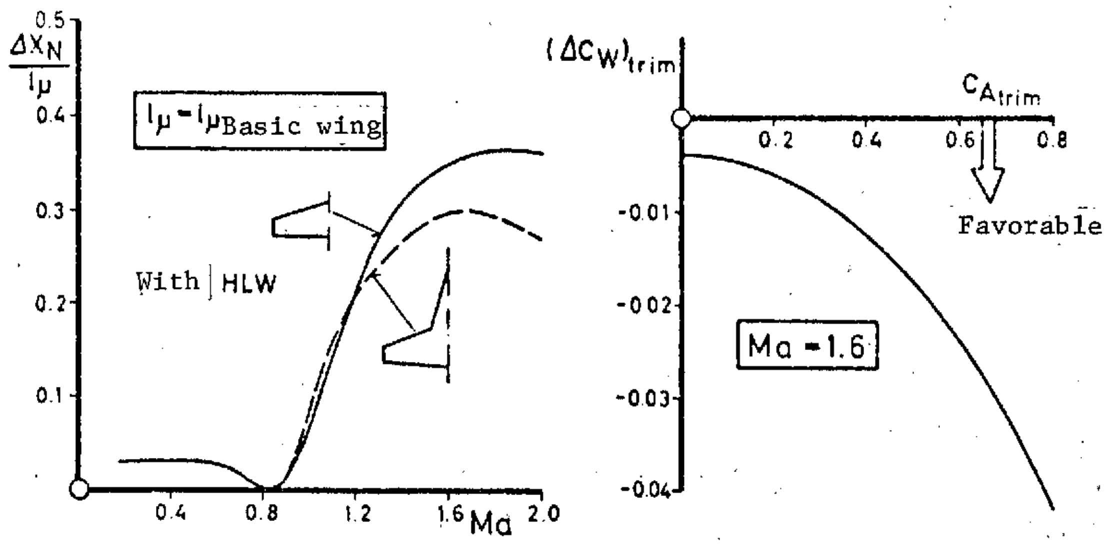

Figure 13. Influence of strake on Mach number dependent neutral point position and on supersonic trimmed drag

REFERENCES

1. Ray, E. J. and R. T. Taylor. Buffet and Static Aerodynamic Characteristics of a Systematic Series of Wings Determined from a Subsonic Wind Tunnel Study. NASA TN D-5805, 1970.

2. Ray, J. E., L. W. McKinney and J. G. Carmichael. Maneuver and Buffet Characteristics of Fighter Aircraft. AGARD, Lisbon, April 26-28, 1972.

3. Polhamus, E. C. A Concept of the Vortex Lift of Sharp Edge Delta Wings Based on a Leading Edge Suction Analogy. NASA TN D-3767, 1966.

4. Hollingsworth, E. G. and M. Cohen. Comparison of Wind Tunnel and Flight Test Techniques for Determining Transonic Buffet Characteristics on the McDonnell Douglas F-4 Airplane. AIAA Paper No. 70-584, 1970.

5. Mabey, D. G. Comparison of Seven Wing Buffet Boundaries Measured in Wind Tunnels and in Flight. ARC CP 840, 1964.

6. Damstrom/Mayes. Transonic Flight and Wind Tunnel Buffet Onset Investigation of the F-8D Aircraft - Analysis of Data and Test Techniques AIAA Paper No. 70-341, 1970.

7. Staudacher, W. A Concept for Determining the Nonlinear Behavior of Double Delta and Strake Wings. MBB Rep. UFE 877-72,(Report under preparation).

Translated for National Aeronautics and Space Administration under contract No. NASw 2483, by SCITRAN, P. O. Box 5456, Santa Barbara, California, 93108.

STANDARD TITLE PAGE

1. Report No. NASA TT F - 15,406	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle IMPROVEMENT OF MANEUVERABILITY AT HIGH SUBSONIC SPEEDS		5. Report Date March 1974
		6. Performing Organization Code
7. Author(s) W. Staudacher		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address SCITRAN Box 5456 Santa Barbara, CA 93108		11. Contract or Grant No. NASw-2483
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of: "Verbesserung der Manöverleistungen im hohen Unterschall," Deutsche Gesellschaft fur Luft und Raumfahrt, Symposium uber Tragflugel-Aerodynamik bei Schallnahen Stromunger, Gottingen, West Germany, Paper 72-126, October 26, 27, 1972, 24 pp.

16. Abstract

Results of a series of experimental studies regarding the improvement of the maneuverability of fighter aircraft. The applicability of slotted and unslotted leading edge and trailing edge flaps was tested up to the transonic region on a wind tunnel model as a geometrically variable configuration variant. As a geometrically fixed configuration variant, strakes, or high sweepback leading edge modifications, were attached to the basic delta wing at the wing root and were tested in the entire Mach number range of a fighter aircraft. Through a combination of the maneuver aids improvements of more than 100% over the basic wing could be achieved in certain flight ranges. The efficiency of the strake in the range of high angles of attack considerably exceeds that of the flap system.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified - Unlimited

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 18	22. Price